Using sensor systems and standard project models to capture and model project history for building commissioning and facility management

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Outline

- Problem Statement
- Motivating Technologies
- Research Projects
  - ASDMCon
  - Product History and RFID
  - IFCs and Building Commissioning
- Conclusion

Problem Statement

- Not having a complete *project history of as-built conditions* of facility components can result in a waste of time and money during operation and maintenance.
  - The San Francisco Airport Authority estimates that 10% of the work hours of its 300 engineers (~$1.5 million/year) are spent searching for facility information [Fischer 1999]
- Accessing the *history of a component* is necessary for efficient and effective diagnostics during facility management.
- Building commissioning data can be utilized throughout the life cycle of a facility.

Motivating technologies and efforts

- For capturing and analyzing a project's history
  - Laser scanners
  - Embedded sensor systems

- For capturing and accessing a product's history
  - Radio Frequency Identification Tags

- For transferring data from building commissioning
  - Industry Foundation Classes

Research Projects

- ASDMCon: Utilizing laser scanners, embedded sensor systems and Industry Foundation Classes for capturing and modeling a project’s history.
- RFID for capturing a product’s history
- Evaluation of IFCs for Building Commissioning

ASDMCon

Advanced Sensor Based Deviation Detection and Management at Construction Sites

http://www.ce.cmu.edu/~itr/

Carnegie Mellon

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ASDMCon Participants

Faculty:
CEE: Burcu Akinci, Jim Garrett, Mark Patton

Robotics: Martial Hebert, Scott Thayer

Architecture: Ramesh Krishnamurti

Postdocs:
Robotics: Daniel Huber, Nicolas VanDapel (P)

Graduate Students:
CEE: Frank Boukamp, Chris Gordon, Sameer Khadkatkar (P)

Robotics: Ed Latimer, Rajiv Saxena, DeWitt Latimer (P), Bob Wang (P)

Architecture: Kuhn Park

Undergraduates:
CEE: Sarah Schrass, Martha Alunkal(P)

ECE: Peter Allen

Robotics: Lisa Michaux-Smith, Jennifer Lin

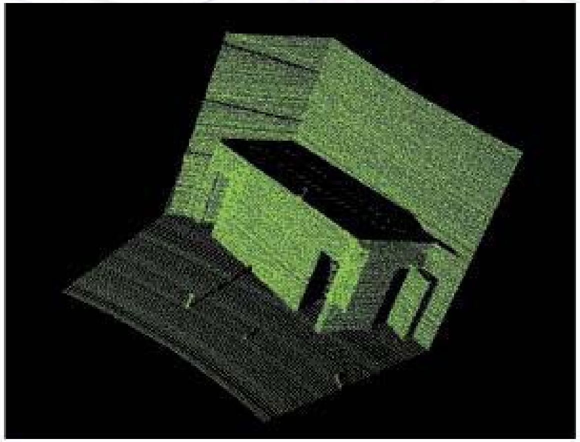
Architecture: Don Havey, John Oduroe (P)

Motivating Technologies

- Laser scanners for quickly creating 3D models of the built environment.
- Embedded sensors to monitor performance of components and materials.
- Integrated project models (e.g., IFC, CIMSteel, etc.) to transfer data and to create an integrated as-designed and as-built models.

Laser scanners enable building 3D as-built models

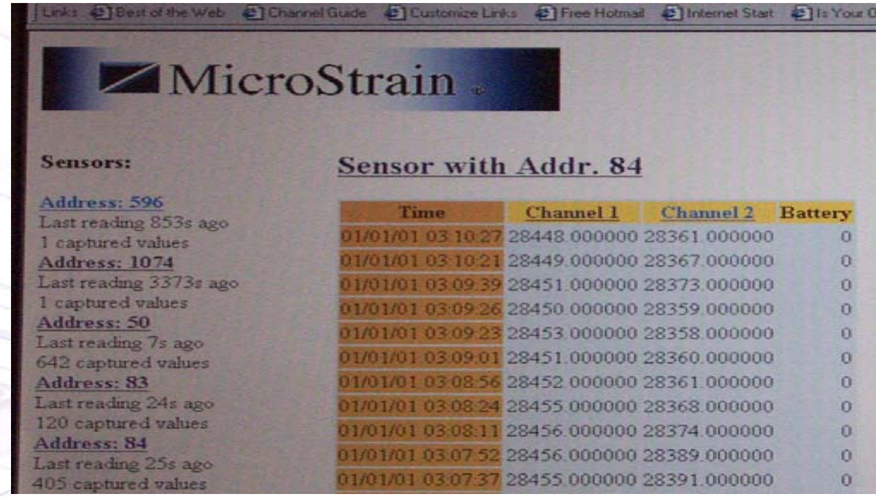
- Example from a warehouse project



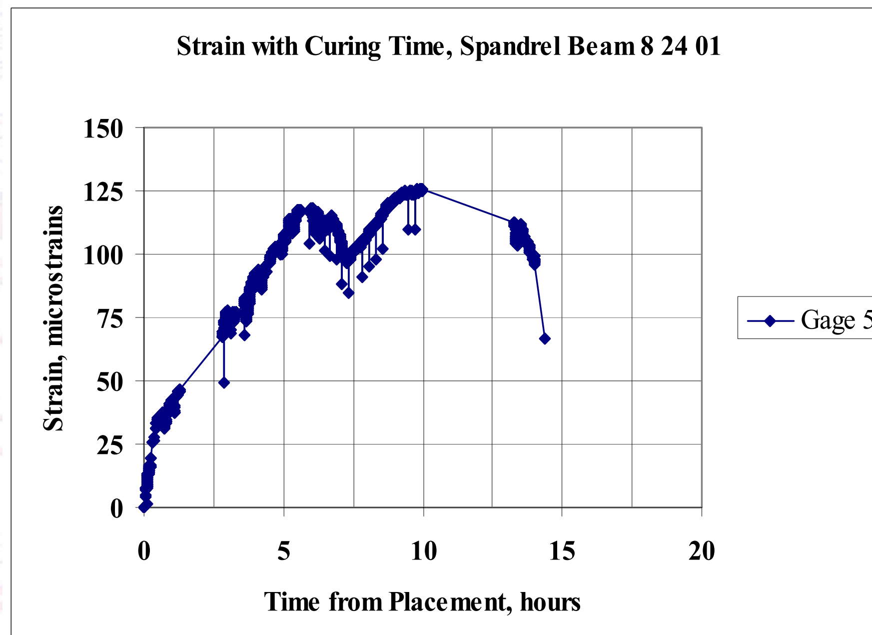
Embedded sensors enable collecting quality info

- Capabilities of certain embedded sensing systems
  - Strain gauges
    - Nucleation and growth of cracks
    - Estimate of shrinkage
    - Estimate of set time and curing rate
  - Temperature gauges
    - Maturity - accurately predict strength
    - Maturity – compliance of mix with specifications
    - Information about curing environment
  - RFID tags
    - ID information, and any programmable information
- Wireless technologies to collect the information

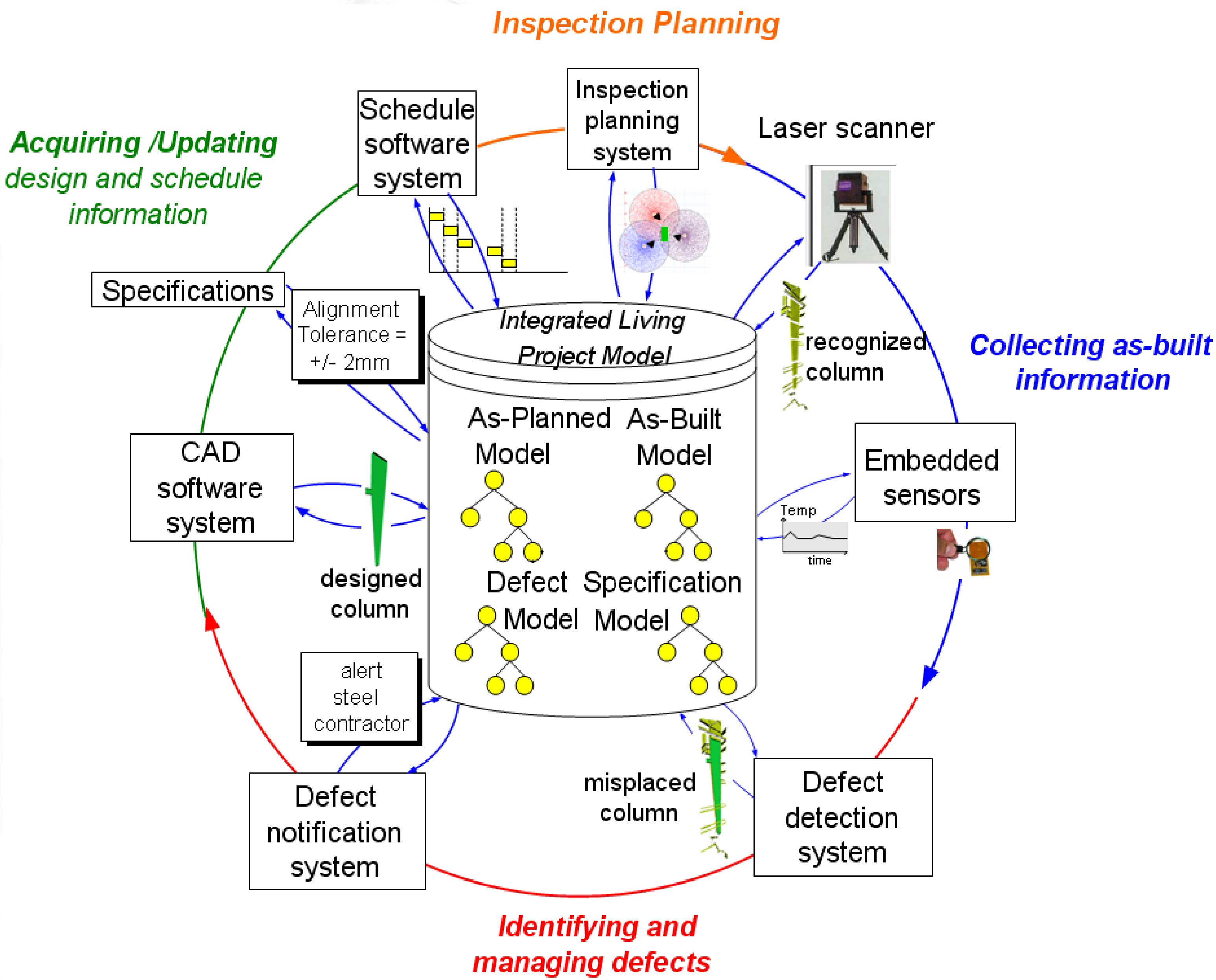
Embedded sensors enable collecting quality info



Time	Channel 1	Channel 2	Battery
01/01/01 03:10:27	28448.000000	28361.000000	0
01/01/01 03:10:21	28449.000000	28367.000000	0
01/01/01 03:09:39	28451.000000	28373.000000	0
01/01/01 03:09:26	28450.000000	28359.000000	0
01/01/01 03:09:23	28453.000000	28358.000000	0
01/01/01 03:09:01	28451.000000	28360.000000	0
01/01/01 03:08:56	28452.000000	28361.000000	0
01/01/01 03:08:24	28455.000000	28368.000000	0
01/01/01 03:08:11	28456.000000	28374.000000	0
01/01/01 03:07:52	28456.000000	28389.000000	0
01/01/01 03:07:37	28455.000000	28391.000000	0



ASDMCon Approach



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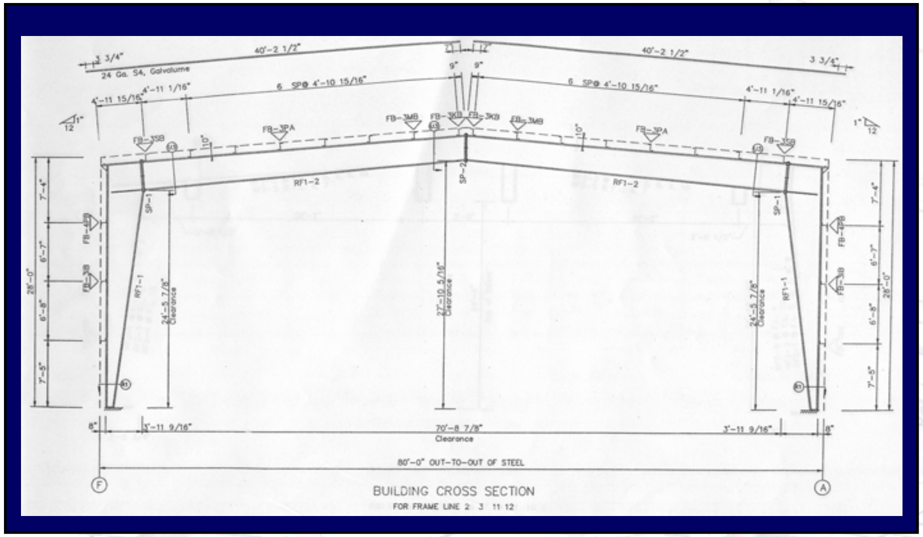
Research Areas/Objectives

- Scan planning
  - Developing general “next-best-view” algorithms
- Sensor and inspection planning
  - Developing formalisms to strategies for allocating sensors to gather the relevant quality related information.
- Object recognition
  - Developing mechanisms for recognition of facility components
- Integrated “living” project models
  - Developing a representation schema and mechanisms for storing multiple views in a project model (creating true 3D design models).
  - Developing a construction specifications model within the integrated project models.
- Automating the analysis of as-built conditions
  - Developing a formalism to identify and categorize significant deviations.

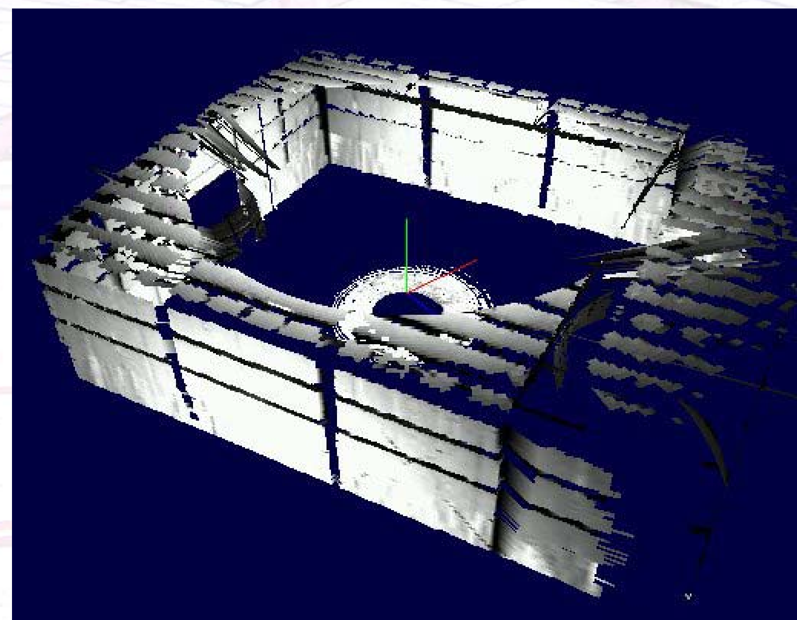
A warehouse project



AISC Code of Standard Practice – Section 7.5.1.:

Anchor bolts and foundation bolts are set by the owner in accordance with an approved drawing. They must not vary from the dimensions shown on the erection drawings by more than the following: ...

(e) ***¼-inch from the center of any anchor bolt group to the established column line through that group....***

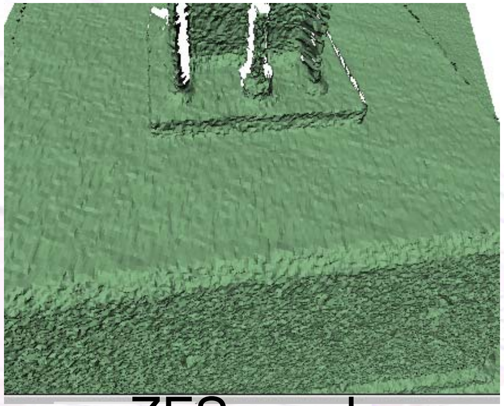


Laser Scanning Process

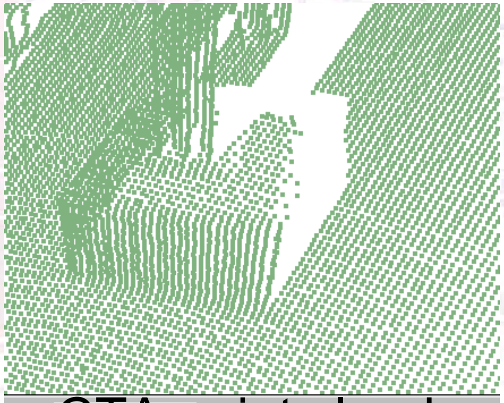
- Used two different laser scanners:
- Zoller + Fröhlich LARA 25200
  - Scans 360° horizontally and 70° vertically
  - captures range and reflectance data for each point
  - maximum range: 25 meters
  - ~90 seconds to complete a scan
    - → ~6 minutes per scan (spin-up time + interface navigation + scan)
- CTA research scanner
  - A research test-bed, composed of two actuated SICK lasers, each able to scan a 180° line
  - maximum range: 80 meters
  - ~45 seconds to complete a scan
    - → ~2 minutes per scan (spin-up time + interface navigation + scan)

Laser Scanning Process

- Which scanner to use?
  – Determined by scale and detail required for each measurement goal
- Z+F scanner:
  + High data density and quality
  – Range data that exceeds 25 meters wraps around to 2 meters, causing overlap of far data with near
- CTA test-bed:
  + Range of 80 meters can make construction applications of laser scanning time-effective
  – lower data density and quality

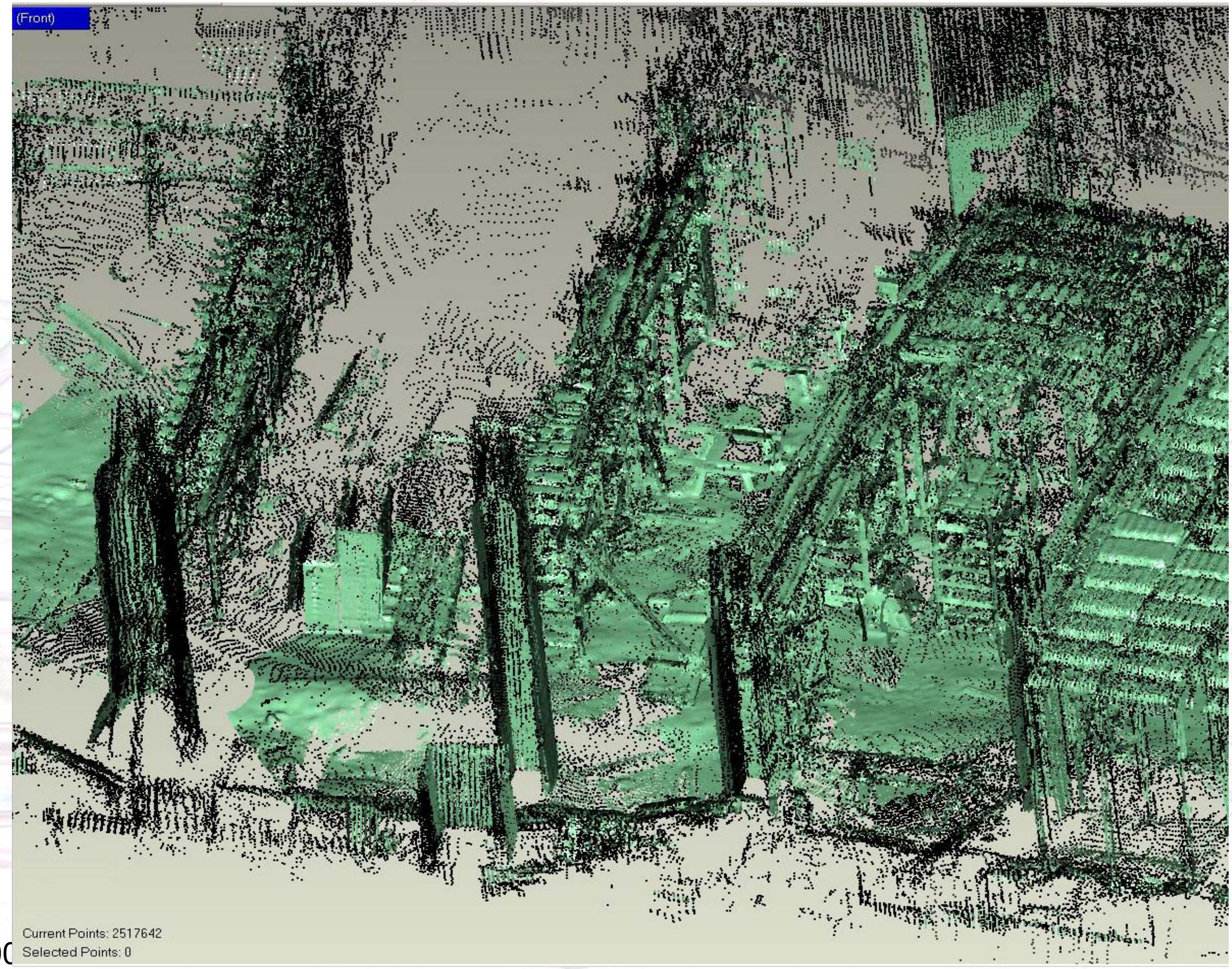


ZFS mesh



CTA point cloud

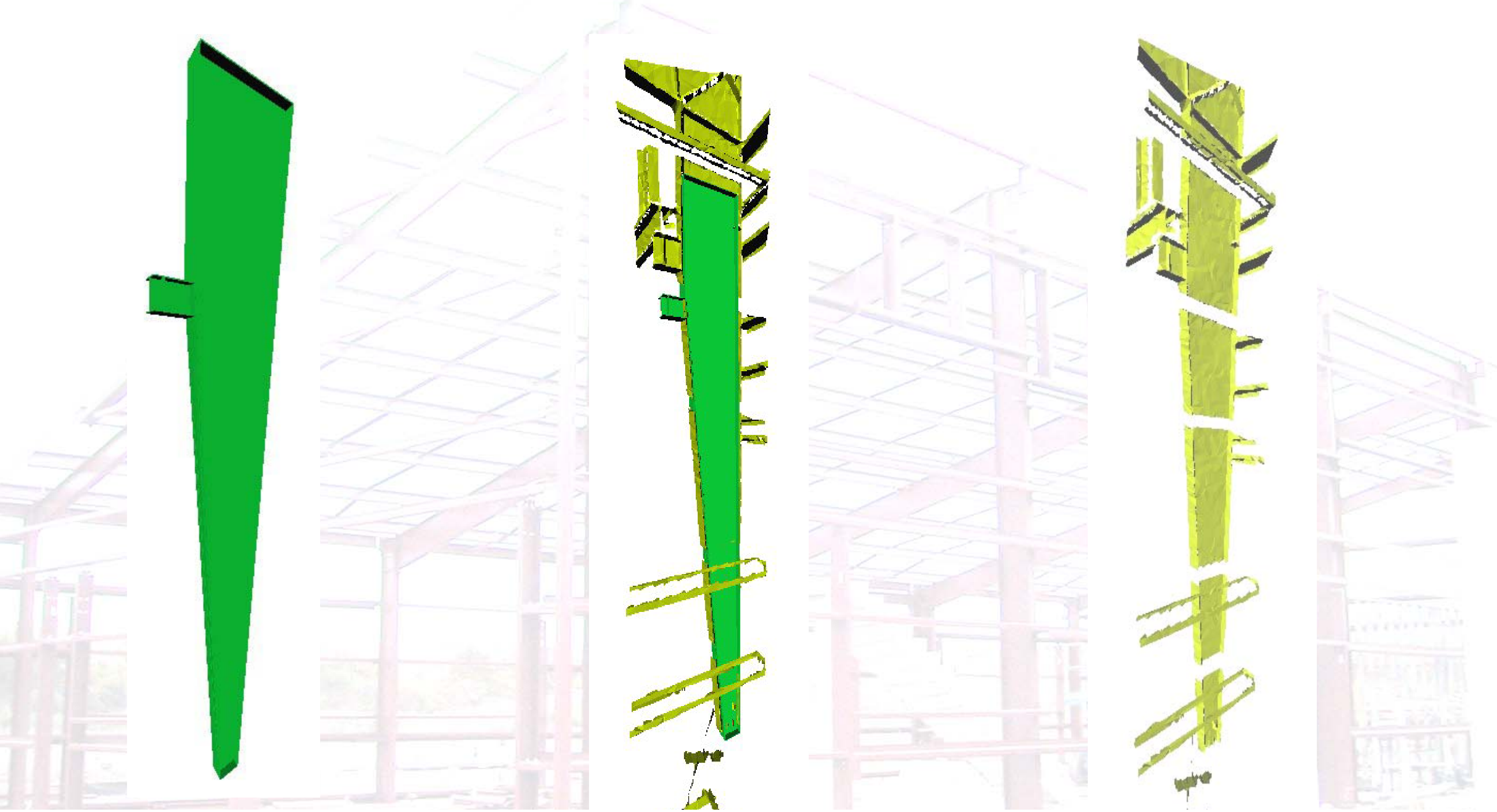
A laser scan of a portion of a current site



Laser Scanning Conclusions

- Total saturation of the construction environment with laser scans is inefficient and can be ineffective.
- Sparse scanning risks missing areas of interest that may be occluded or otherwise hard to access for necessary measurements.
- Quality of scans generated is highly dependent on the scan plan.
- Goal:
  - Optimizing the use of scanners to achieve a given set of measurement goals in the built environment
  - Minimize cost of scanning
- Input: Information goals, determined based on
  - Design info
  - Schedule info
  - Construction specification info
  - Previous as-built info

Object Recognition Process



•Easiest objects for the system to recognize are often the hardest objects to model with a CAD system.

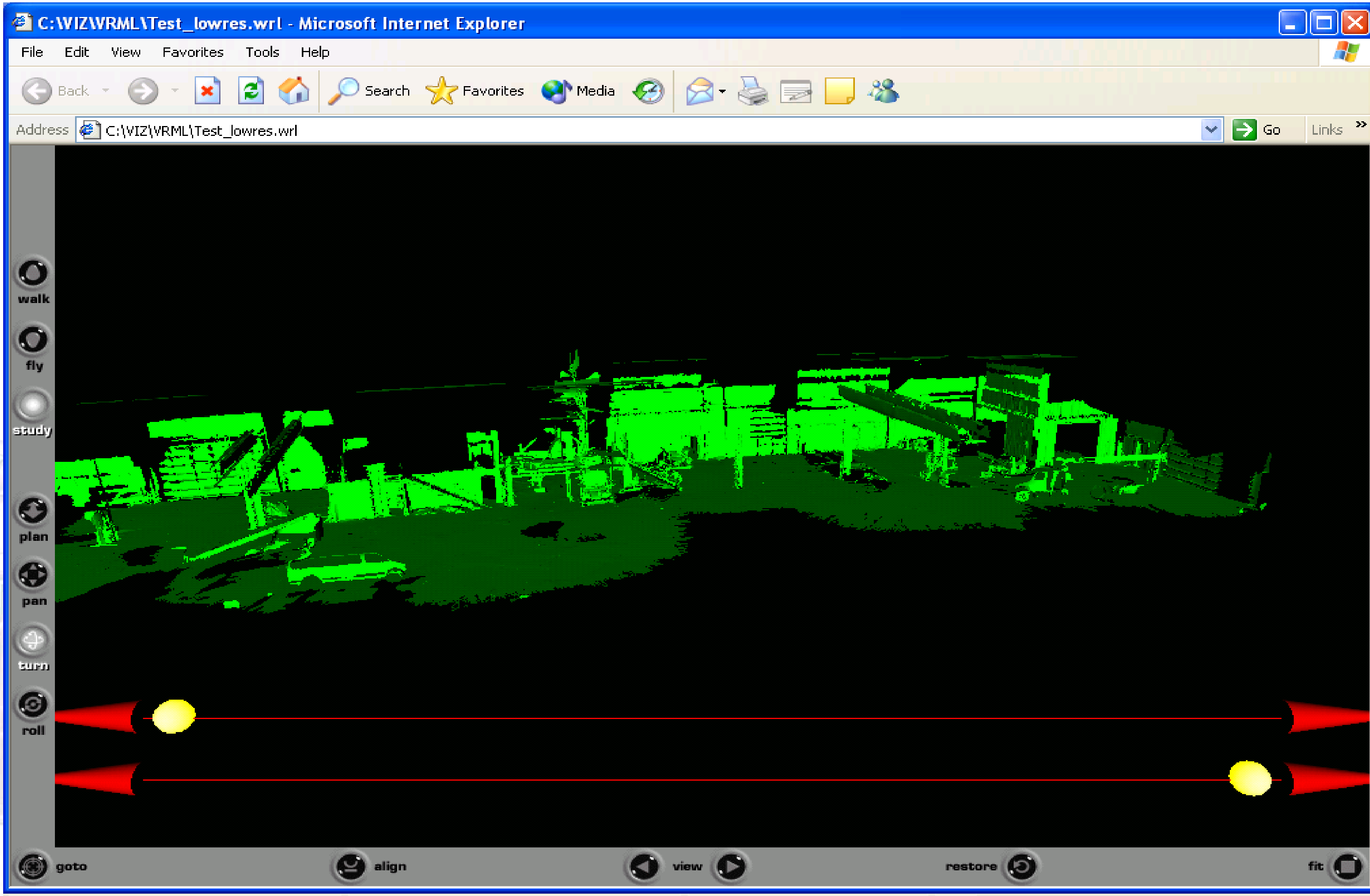
Embedded Sensing

Identification of discrepancies

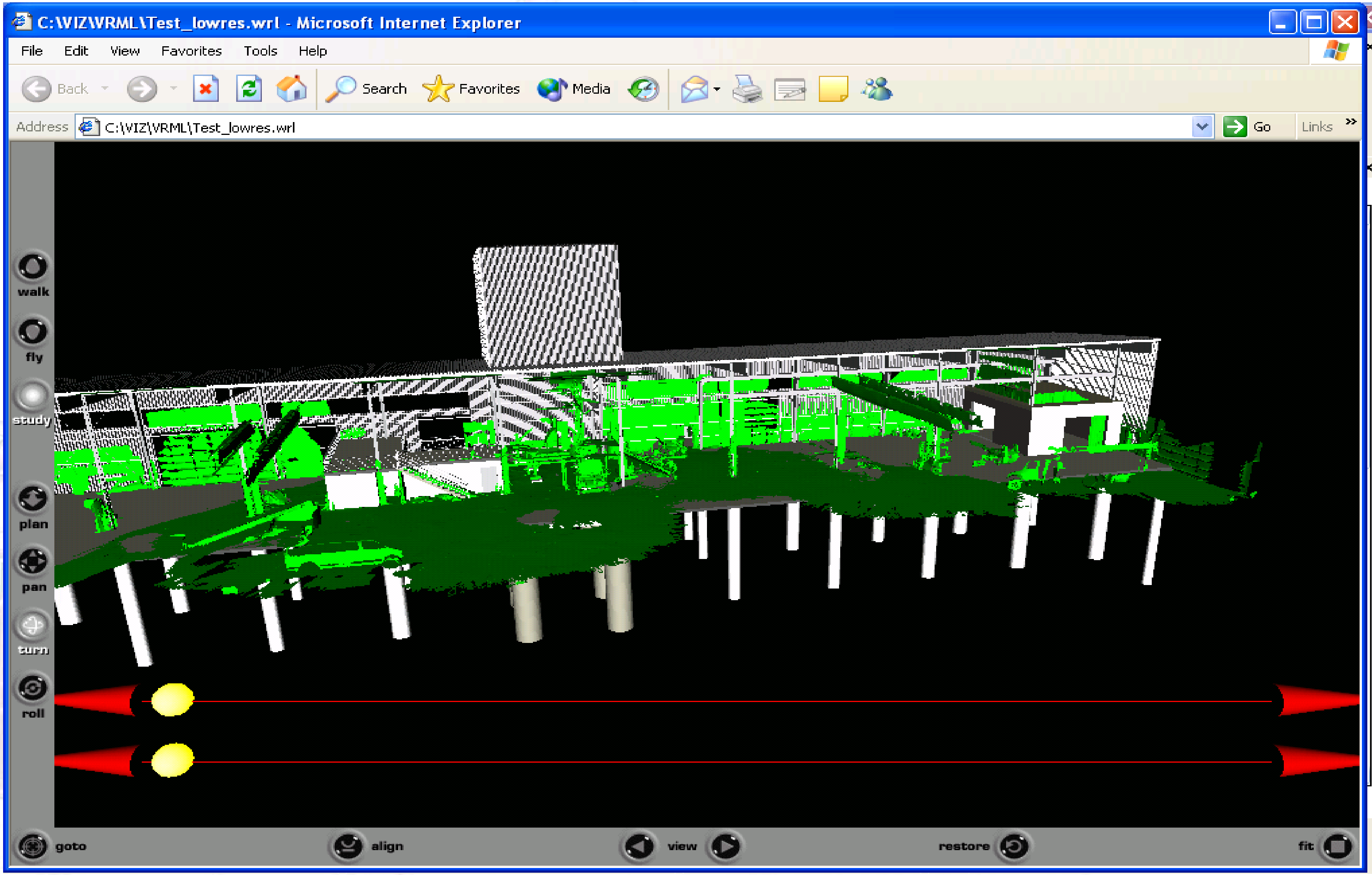
- Short-term approach – Visual inspection:
  - Overlay 3D design model and 3D as-built model to look for discrepancies

- Long-term Vision – Automation:
  - Automating the process of comparing as-built and design models

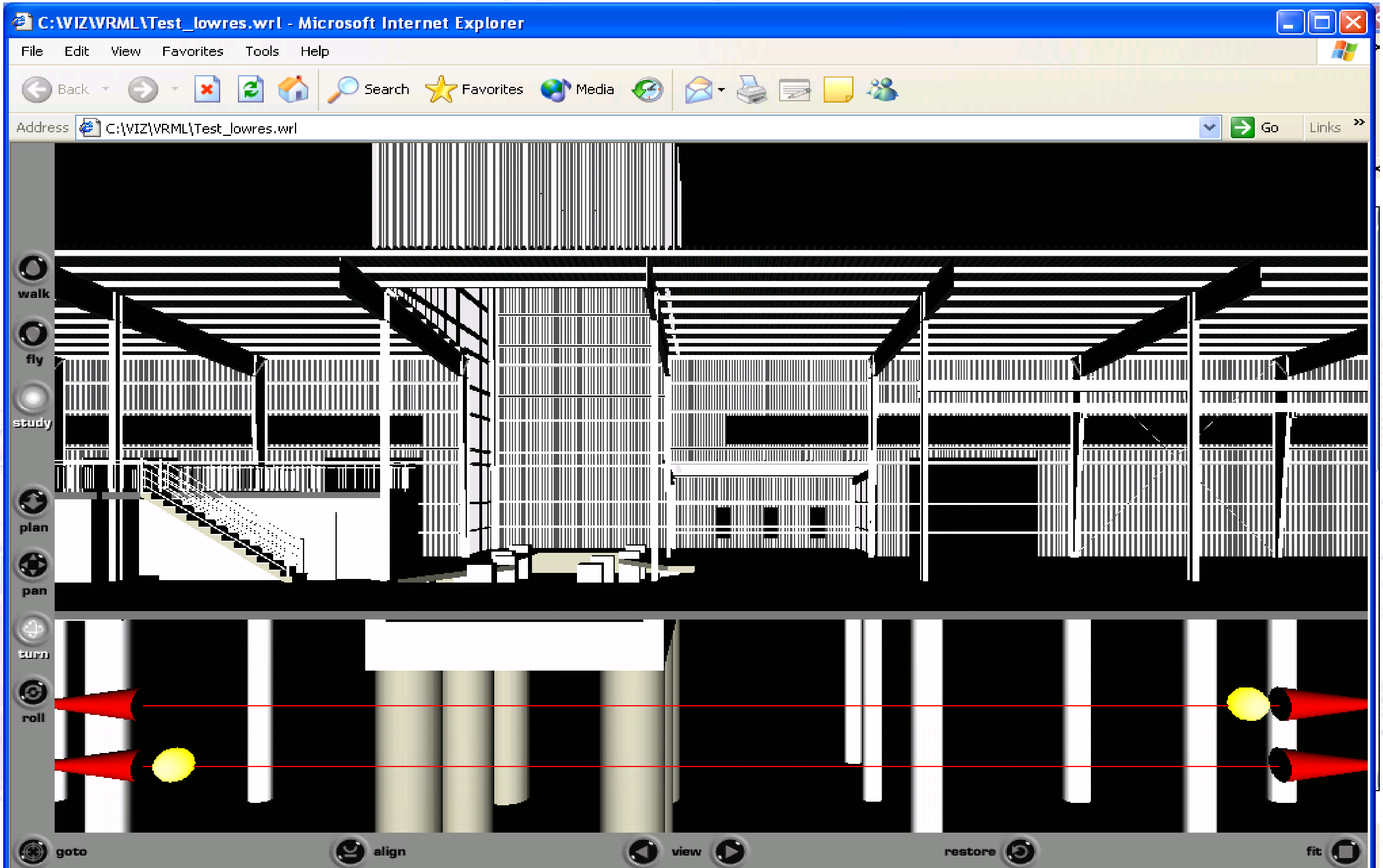
Situation assessment: Assessment of as-built conditions



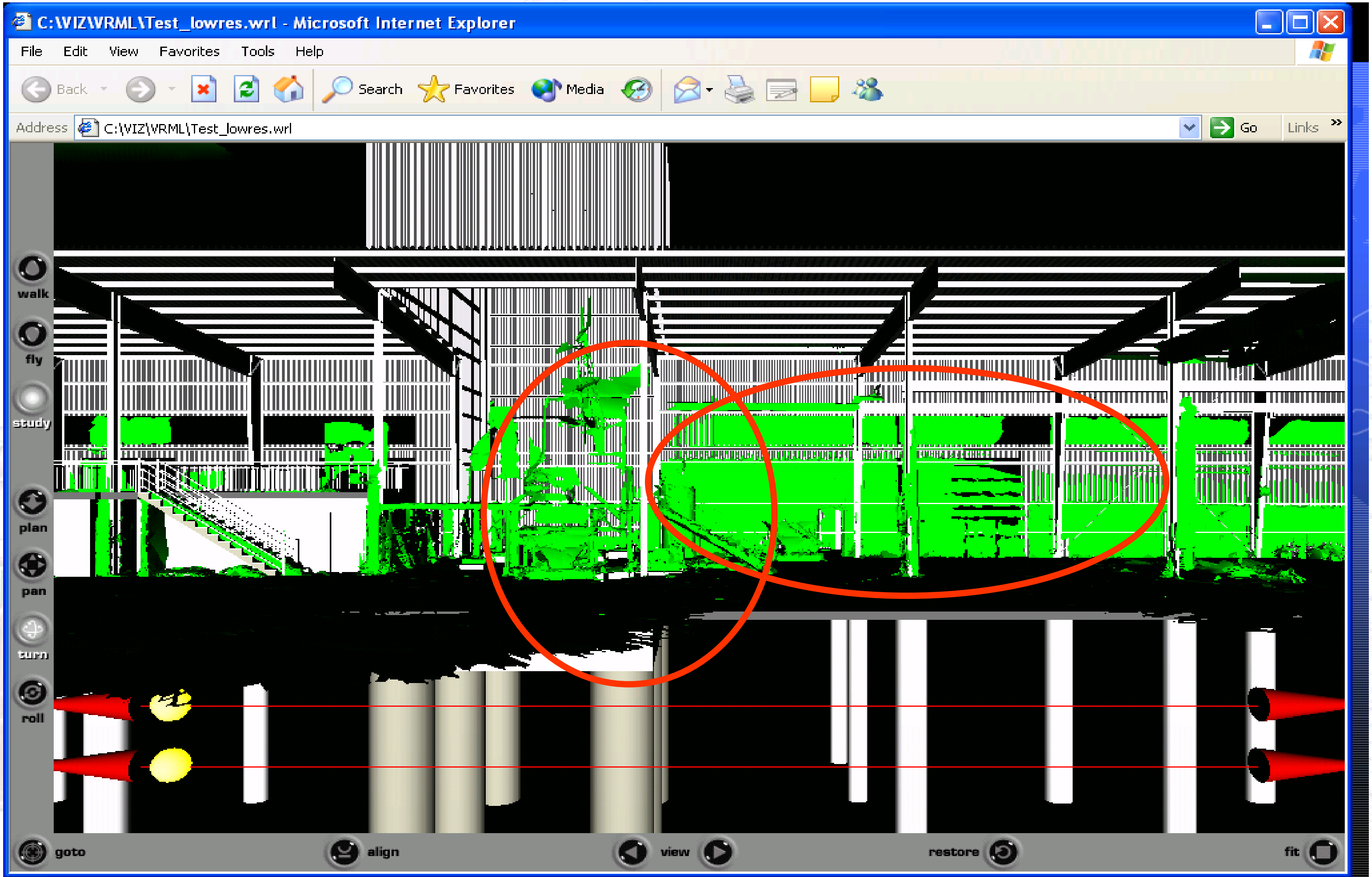
Situation assessment: Integration of design and as-built



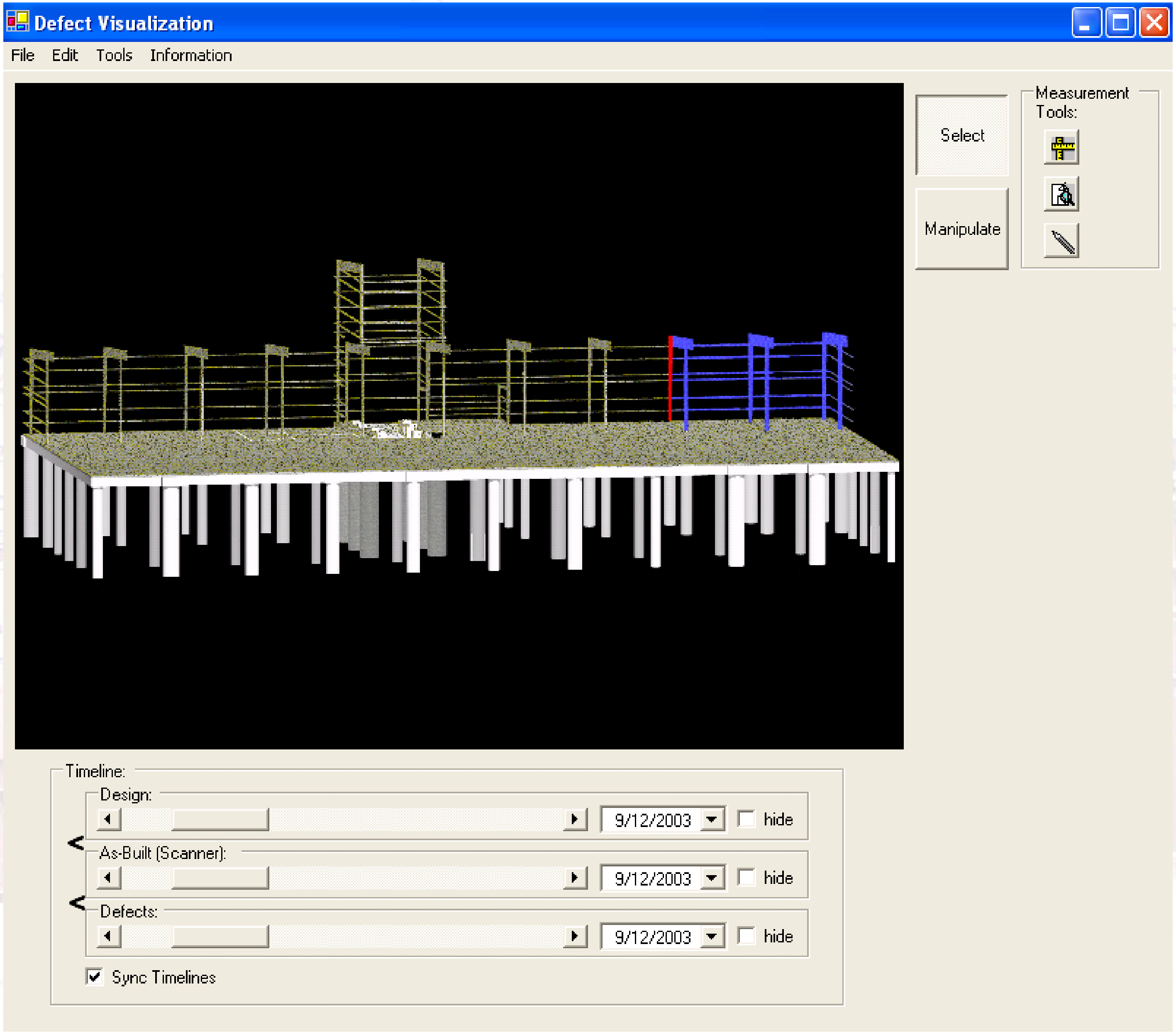
Integration of design and as-built is valuable



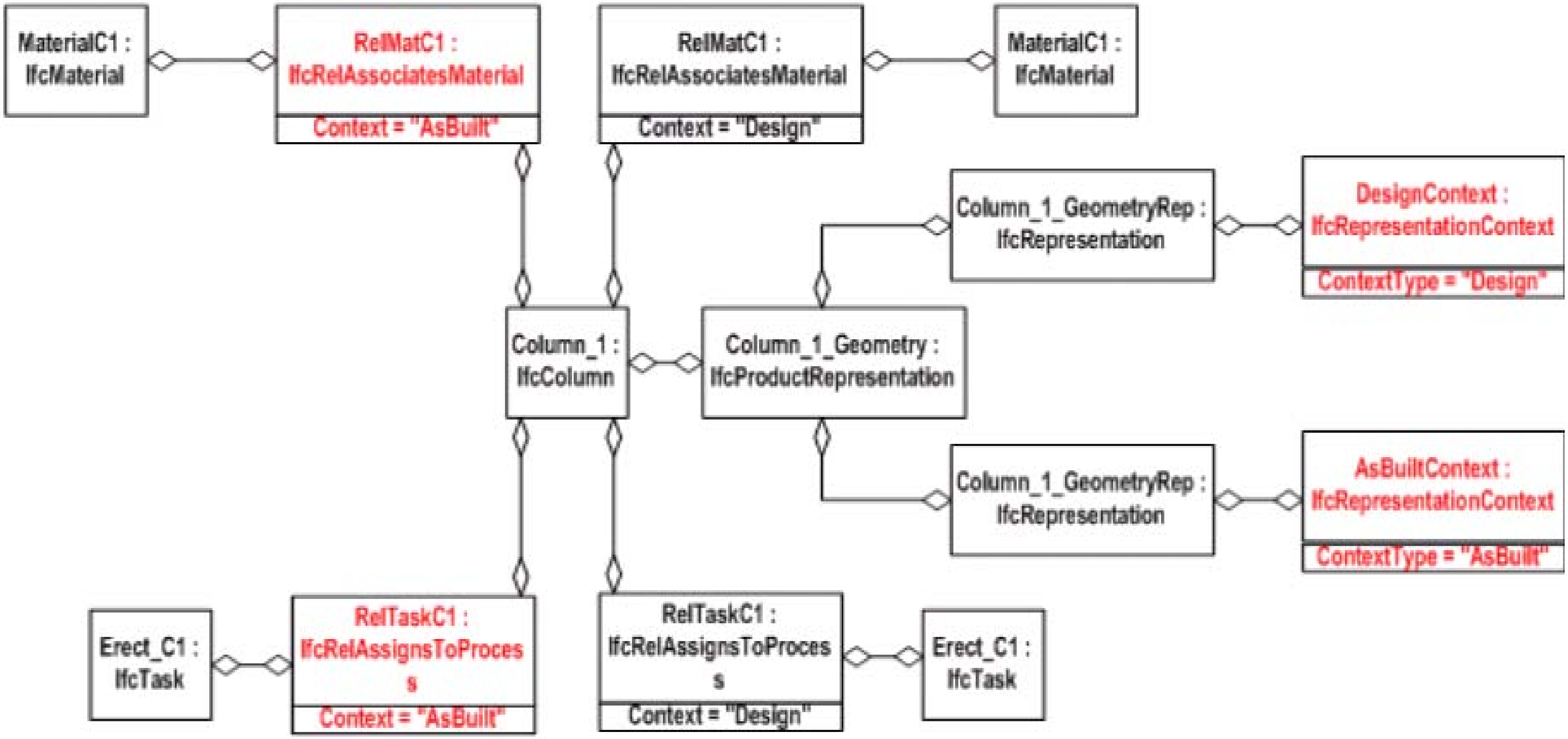
Integration of design and as-built is valuable



Project history visualization environment



Modified IfcRelationship-Class



ASDMCon Conclusions

- Laser scanners and embedded sensors can be deployed to collect as-built construction information with project-team cooperation.
- The usage of these devices should be carefully planned.
- The data collected from these devices should be processed and analyzed.
- Current project models need to be enhanced to be able to represent the history of a project.

Utilizing Radio Frequency Identification for Capturing the History of Building Components

Burcu Akinci, Esin Ergen, Rafael Sacks

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Historical information is needed to understand why a crack exists

-Date of production
-Material types/Mill reports
-Manufacturing Inspection reports
- Storage conditions

Stored by the manufacturer in paper-based format during production

Usage conditions and related important events

Stored in memos within the FM company during operations

- Any damage during transportation and installation
- Installation process and conditions

Stored in memos between supplier and contractor and contractor's database

Need for a data collection and storage system

An automatic data collection and storage system:

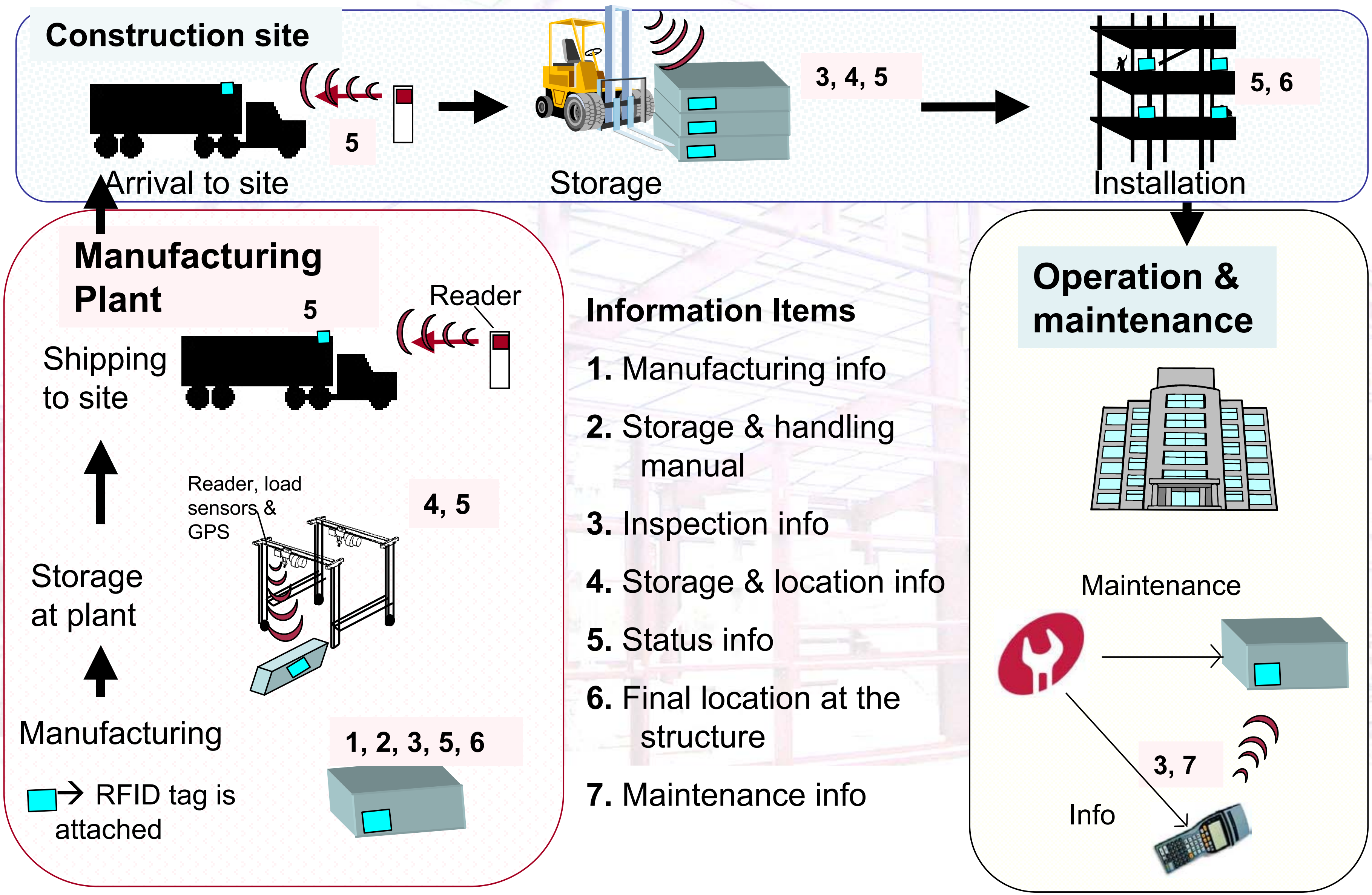
- to capture the status information at various milestones.
- to integrate this data in a database automatically to minimize errors and to enable real-time reporting.
- to transfer relevant information about a component with the component.

➔ Leverage RFID, DGPS and load sensor technologies.

➔ Goal: Achieve Level 1 intelligence on building elements:

  - ➔ Has a unique identification,
  - ➔ Is capable of communicating its status (form, composition, location, key features) effectively with its environment
  - ➔ Is capable of storing data about itself (current and historical data)

Approach for capturing and storing a component's history on a component



Results and Conclusions

- Performing several pilot case studies in a precast manufacturing and a pipe spool manufacturing plants.

- The initial results of a field test done at a pipe spool manufacturing plant showed that
  - active tags operating at 433.92 MHz frequency at a read/write distance of 60-150 feet and having a memory up to 0.5 MB work well for storing some information on the tag and reading id and other information from multiple tags in a short period of time is viable [FIATECH 2004].

  - some technical limitations, such as metal interference, that were experienced in the trials appeared to be resolved with relatively minor adjustment to the work procedure [FIATECH 2004].
- Further work is being done to identify the information items that should be stored on these components.

Testing the capabilities of IFCs for transferring building commissioning data

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Tanyel Turkaslan-Bulbul, Hongjun Wang, Ipek Gursel

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NIST

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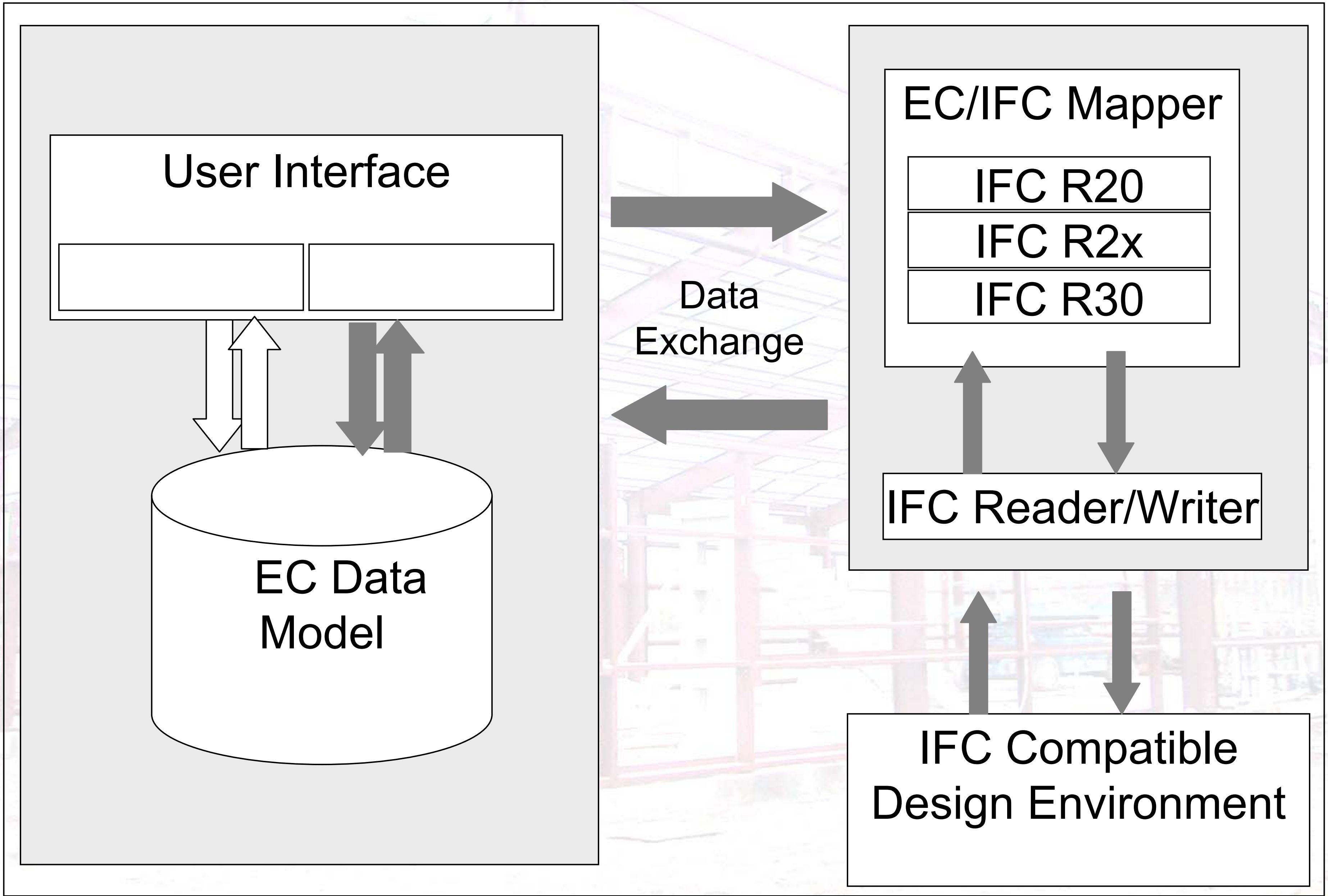
Embedded Commissioning

- ASHRAE defines commissioning as the process of ensuring that systems are designed, installed, functionally tested and capable of being operated and maintained to perform in conformity with the design intent (Guideline 1-1996).

- The role of embedded commissioning is to complement each of the lifecycle phases and their interactions through timely building system evaluation.

- To be able to support this, current standardization efforts, such as Industry Foundation Classes, need to represent the building commissioning data to be exchanged at different phases.

Approach



User Interface
EC Data Model
Data Exchange
EC/IFC Mapper
IFC R20
IFC R2x
IFC R30
IFC Reader/Writer
IFC Compatible Design Environment

Results and conclusion

- Performed a small test case consisting of fan and air filter.
- Tested the data exchange between our BC model and IFC Rel 2 and Rel 2x2.
- Using IFC Rel 2, we were able to exchange about 60% of the data.
- Using IFC Rel 2x2 class specifications and the property sets, we were able to exchange 90% of the data.
- Further testing will be done with additional classes.

Overall Conclusions

- The capabilities of data capture technologies is significantly getting better.
- Need for developing formalisms for planning the usage of these technologies and analysis of the data captured by these technologies.
- Standard data models are getting better in representing building commissioning and project history related data.